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GLASS FOR FIBER OPTICS (REVIEW)

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The published and patent data on the compositions of glass for optical glass fibres, production technology, and the basic requirements imposed on this glass were analyzed. Synthesis of glass for the light-conducting core in the $BaO - B_2O_3 - La_2O_3 - SiO_2$ system was proposed using modern methods of production of optical glass fibers.

Fiber optics is a promising direction in industrial production, and research in this area should be developed further. The 1960s can be considered the beginning of the modern stage — the time of industrial implementation of the first fiber optic elements for use in instrument building. The use of light guides is highly effective and boundless. Today they are used in space and laser engineering, and in electronic and optical transducers for night vision instruments in modern observation systems. The transmission speeds of modern fiber-optic systems reach 1 – 10 Gbits/sec, which allows sending gigantic masses of data in one channel (up to 2 million telephone calls or 2000 television programs simultaneously). The domestic and world market is now undergoing high demand for fiber-optic elements due to the rapid rates of development of production of the basic components in fiber-optic data transmission systems.

Optical glass is still the basic material for manufacturing fiber-optic elements for different applications. The refractivity and dispersion (Abbe number) are its most important properties except for light transmission.

An important number of studies on developing glass compositions for fiber optics were conducted in the middle of the last century in such countries as the USSR, USA, Korea, China, Japan, the FRG, Czech Republic, and France. After the collapse of the USSR, there were few studies in this area in the entire post-Soviet region. The basic manufacturers of light guides are now China, Germany, the USA, and Japan. An analysis of patent data sources shows that the manufacturing countries use glass compositions based on lanthanum, niobium, gallium, titanium oxides, and other components.

The optical glass fiber is a system that consists of a light-conducting core and one or two light-reflecting coatings. The fiber optical element consists of separate glass fibers which are positioned by different methods. The coating fulfills several functions: it protects the surface from contaminants, provides for optical insulation between neighboring fibers, and is used for obtaining air-tight fiber composites. The aperture number, determined with the following equation, is the basic parameter of the light guide:

$$A = \sqrt{n_l^2 - n_c^2},$$

where n_l and n_c are the refractive indexes of the light-conducting core and the coating.

For the fiber to conduct light with minimal losses and the fiber component to have the required frequency-contrast characteristic, the value of the aperture number must be higher than 0.8 [2].

Optical glasses for fiber optics must ensure stable physicochemical properties in exposure to extreme external factors. They are also used to create inhomogeneous or composite optical media. Requirements which are not characteristic of glasses in classical optics are imposed on glasses for fiber optics:

to ensure the required numerical aperture of the light guide, the glasses of the fiber coating and core must have a certain difference in the squares of the refractive indexes of the glasses of the light-conducting core and the light-isolating coating;

for the thermomechanical strength of the light guide, the CLTE of the coating glass must be lower than the CLTE of the light-conducting core glass;

to prevent the appearance of diffusion on the core – coating boundary, the viscosities of the core and coating must minimally differ; however, the viscosity of the coating must be slightly higher because it determines the conditions of the fiber-drawing manufacturing process [3].

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The coating and core glasses must be selected based on the CLTE not only between themselves but also between the parts with which the fiber element will be joined. It is technologically necessary for the CLTE of the coating glass to be $(2 – 10) \times 10^{-7}\ K^{-1}$ less than the CLTE of the core glass. In this case, the fiber coating will be in a compressed state, which will increase the mechanical strength of the fiber. This ratio of the CLTE is mandatory in fabrication of flexible light guide bundles.

When light passes through a light guide, optical losses caused both by its structure and by the properties of the material used to make it occur. These losses are characterized by the magnitude of the attenuation of the light energy which should not exceed 0.3 – 0.7 dB/km for main fiber-optic communications lines [4]. The existence of such a concept as "window of transparency," which means the long-wave range in which light is propagated along a fiber with low attenuation, should be noted. There are three such ranges: 820 – 850 nm, and also in the 1300 and 1550 nm regions. For this reason, there are also regions of high attenuation, which are located near 730, 950, 1250, and 1380 nm [5].

On the whole, the optical light guide has a complicated structure that creates conditions for passage of light along the axis of the fiber by total internal reflection with minimal losses.

Glass compositions from the flint glass group are used for production of the light-conducting core: heavy barite (HBF) and extra-heavy barite (EHF), and glasses from the crown glass group are used for the coatings. The refractive index n_D and the average dispersion coefficient υ_D are the basic characteristics of optical glass. For flint glass, n_D varies from 1.5247 to 2.05 and υ_D varies from 17 to 56, while they vary from 1.4704 to 1.6568 and 51.1 to 70, respectively, for crown glass.

The basic components of HBF are lanthanum, barium, niobium, titanium, and rare-earth element oxides. The glass in these systems is characterized by high crystallizability, the cause of data losses.

The effect of CdO on glass formation and the optical properties of borosilicate glass was investigated in [6]. The results showed that cadmium glasses have low crystallizability and high chemical stability. Cadmium oxide is well assimilated by glass in a content of up to 40%;[2] CdO increases the refractive index of glass by almost the same degree as lead oxide, but increases the dispersion much less; however, its use is undesirable due to the toxicity [7].

Incorporation of thallium oxide in optical glass (US Patent No. 4495298) results in a more homogeneous glass melt, but on the other hand, the thallium ion is more volatile than any other alkali metal ion. Volatilization of Tl_2O increases exponentially with an increase in the melting temperature, so that synthesis of this glass is expediently conducted at temperatures of 1350 – 1400°C. The limits of the molar content of thallium oxide in the glass are 45 – 70%. At a lower Tl_2O content, the lifetime and chemical stability of the glass article decrease sharply, and when the content is above the limit, the melting temperature of the glass increases. Satisfying these conditions makes it possible to obtain low-melting, highly stable and homogeneous articles. Thallium glass has a low tendency to crystallize, which allows melting it in high-volume vessels. However, due to the toxicity of thallium oxide, the glass must be melted without allowing it to enter the atmosphere.

In the last decades of the previous century, new types of glass obtained from oxides not previously used in glass melting were investigated. The results of studying the crystallizability, optical properties, and density of gallium sodium-borosilicate glass and glass formation and the properties of the glass in the ternary $B_2O_3 – Ga_2O_3 – PbO$ system.

These glasses were synthesized by incorporating gallium oxide in the cullet of the "initial" glass. The glasses containing approximately up to 20% Ga_2O_3 do not crystallize in prolonged (up to 12 h) holding in a gradient furnace. At a Ga_2O_3 content above 20%, they tend to crystallize. In this system, a relatively large glass formation region was found even in melting the glasses in large quantities followed by fine annealing. The maximum Ga_2O_3 content in the three-component systems forming the glasses is slightly higher than 30%. The refractive index of the glasses varies within a very wide range, from 1.62 to 2.11.

Gallium glasses differ from similar lanthanum glasses by their more pronounced flint properties, i.e., for the same n_D, they have lower dispersion coefficients.

As a result of the basic studies in [9], the region of glass formation was established in the $B_2O_3 – La_2O_3 – ZnO$ system, which lies in the crystallization fields of lanthanum and zinc metaborates. The degree of crystallization decreases for compositions outside the field of formation of zinc metaborate. Addition of 5% ZrO_2 (molar content) weakly affects the degree and temperature of the upper crystallization boundaries of glasses located in the lanthanum metaborate crystallization field. At the same time, the degree of crystallization decreases for compositions containing $\leq 10\%$ La_2O_3 (zinc metaborate field), since they pass into the field of baddleyite formation. Addition of 5 and 10% Ga_2O_3 significantly decreases the temperature of the upper crystallization limit (by 100°C and more).

Germanate – borate glass of the HBF type also has high crystallizability. It was noted in [10] that simultaneous separation of three crystalline phases is observed in HBF glass: titanium phase (presence of titanium oxide), cadmium borate, and a third phase that the authors do not name.

The holders of USSR Inventor's Certificate No. 191080 propose an optical glass of the following composition (%) for the core of an optical glass fiber which has a refractive index of 1.7 – 1.8 and is characterized by high chemical stability: 18 – 20 SiO_2, 13 – 14 B_2O_3, 32 – 36 BaO, 15 – 19 La_2O_3, 11 – 13 TiO_2, maximum of 4 ZrO_2, maximum of

[2] Here and below, if not explicitly stated, mass content.

3 Al_2O_3, and maximum of 3 As_2O_3. The proposed composition has a high melting temperature (1550°C) and initial softening point (700°C).

There is an optical glass with a refractive index of 1.9 – 2.1 and a dispersion coefficient of 16 – 23 that contains (%): 6 – 15 SiO_2, 2 – 10 B_2O_3, 67 – 90 PbO, 1 – 10 Al_2O_3, maximum of 10 Ga_2O_3, under 5 L_2O_3, TiO_2, ZrO_2, WO_3, under 3 Sb_2O_3, As_2O_3, and CeO_2 (USSR Inventor's Certificate No. 270216).

The highest refractive indexes, previously ensured by addition of barium and zinc oxides, are now attained by using compositions containing large amounts of lanthanum, zirconium, and niobium oxides.

There is a glass composition for production of the light-conducting core of an optical glass fiber in the La_2O_3 – BaO – SiO_2 system containing (%): > 5 – 15 SiO_2, 20 – 30 B_2O_3, 21 – 30 La_2O_3, 5 – 15 Y_2O_3, 0 – 10 Gd_2O_3, 1 – 8 ZrO_2, 0.1 – 5 Nb_2O_5, 5 – 12 Ta_2O_5, 0 – 10 ZnO, 0 – 10 CaO, 0 – 5 SrO, 0 – 10 BaO, 1 – 8 Li_2O, 0 – 1 Sb_2O_3, 0 – 1 As_2O_3. This composition has a low glass transition temperature (in the 500 – 580°C range). The optical constants of this glass have the following values: refractive index of 1.70 – 1.75, Abbe number of 45.0 – 54.0 (US Patent No. 6753281). The composition is also characterized by a high tendency toward crystallization, which limits its use in industrial production.

US Patent No. 6797659 reports an optical glass composition with a refractive index of 1.75 – 1.85, Abbe number of 35.0 – 45.0, and the following composition (%): 1 – 6 SiO_2, 15.5 – 25 B_2O_3, 25 – 40 La_2O_3, 0 – 6.4 Y_2O_3, 2 – 6.5 ZrO_2, 3 – 12 Nb_2O_5, 1 – 8 Ta_2O_5, 17 – 28 ZnO, 0.6 – 3 GeO_2, 0 – 5 TiO_2, 0 – 5 Al_2O_3, 0 – 1 BaO, 0 – 1 It_2O_3, 0 – 1 Sb_2O_3. The glass transition temperature is 500 – 590°C.

US Patent No. 6818578 proposes a glass composition with a refractive index of 1.875 and dispersion coefficient of 39.5 of the following composition (%): 3 – 10 SiO_2, 7 – 15 B_2O_3, 30 – 60 La_2O_3, 0 – 5 GeO_2, 2 – 8 ZrO_2, 0 – 30 Gd_2O_3, 0 – 10 Y_2O_3, 0 – 5 It_2O_3, 13 – 19 Ta_2O_5, 0 – 15 ZnO. The composition has high refractivity and low dispersion indexes.

The optical glass of the following composition (%): 15 – 25 SiO_2, 0 – 5 B_2O_3, 30 – 50 La_2O_3, 5 – 15 ZrO_2, 0 – 5 CaO, 0 – 10 BaO, 0 – 10 Nb_2O_5, 0 – 5 TiO_2, 0 – 10 Li_2O, 3 – 12 Na_2O, 0 – 10 K_2O, has a refractive index of 1.82, Abbe number of 22 – 28, and initial softening point of 500 – 580°C (US Patent No. 6828265).

The optical glass from the flint glass group with a refractive index of 1.78 – 1.86 has the following composition (%): 20 – 30 P_2O_5, 25 – 50 Nb_2O_5, 0 – 15 Na_2O, 0 – 15 K_2O, 0 – 8 Li_2O, 1 – 7 ZnO, 0.5 – 10 B_2O_3 (US Patent No. 6875714). A drawback of this composition is the presence of phosphorus oxide, which is a volatile component.

The following glass composition (%) is proposed in EPB application No. 1533285: 0.1 – 10 SiO_2, 15 – 35 B_2O_3, 15 – 55 La_2O_3, 0 – 2 Y_2O_3, 0 – 25 Yb_2O_3, 1 – 40 Gd_2O_3, 0.1 – 3 Li_2O, 0 – 10 GeO_2, 0 – 10 ZrO_2, 0 – 10 WO_3, 0 – 15 ZnO, 0 – 10 RO (R^+ — Ca, Sr, Ba), 0 – 5 TiO_2, 0 – 5 Nb_2O_5, 0 – 10 Ta_2O_5, 0 – 1 Sb_2O_3 (0.1 – 10 F^-, above 100%). The glass of this composition has the following characteristics: n_D = 1.75 – 1.80, υ_D = 50.0. The proposed glass composition, like other lanthanum-borosilicate glasses, tends to crystallize with separation of a crystalline phase of $La_2O_3 \cdot 2SiO_2$ (OST 3-776–80).

The composition of phosphorus-free optical glass with a refractive index ≥ 1.83 and Abbe number ≥ 35 includes (%): 2 – 9 SiO_2, 8 – 18 B_2O_3, 35 – 50 La_2O_3, 3 – 20 Gd_2O_3, 4.5 – 7 ZrO_2, 0.1 – 3 Nb_2O_5, 15 – 25 Ta_2O_5, 17 – 28 (Ta_2O_5 + Nb_2O_5), 0 – 3 Li_2O, 0 – 3 WO_3, 0 – 10 ZnO, 0 – 5 Mg(Ca, Sr, Ba)O, 0 – 1 Sb_2O_3. The liquidus temperature of the proposed composition does not exceed 1240°C (EPB application No. 1604959).

A glass composition containing the following (%) is reported in EPB application No. 1640346: 42 – 55 Nb_2O_5, 2.7 Nb_2O_5 (TiO_2), 2 – 8 Li_2O, < 5 Mg(Ca, Sr, Ba, Zn)O, < 5 ZrO_2, 0 – 10 Na_2O, 0 – 20 K_2O, 10 – 25 (Li_2O + K_2O + Na_2O), 0 – 1 Sb_2O_3, 2 – 8 (RO + ZrO_2 + Li_2O). This composition has a refractive index no lower than 1.875, the Abbe number is above 39.5, and the initial softening point is 700°C.

EPB application No. 1637506 proposes an optical glass composition which is an EHF (molar content, %): 45 – 75 Bi_2O_3, 12 – 45 B_2O_3, 1 – 20 Ga_2O_3, 1 – 20 In_2O_3, 0 – 20 ZnO, 0 – 15 BaO, 0 – 15 (SiO_2 + Al_2O_3 + GeO_2), 0 – 15 (MgO + CaO + SrO), 0 – 5 CeO_2, ≥ 5 (Ga_2O_3 + In_2O_3 + ZnO), 0 – 10 (SnO_2 + TeO_2 + TiO_2 + ZrO_2 + Ta_2O_3 + Y_2O_3 + WO_3). This composition is characterized by a refractive index ≥ 2.10.

The optical glass of the composition (%): 0 – 10 SiO_2, 45 – 65 B_2O_3, 5 – 22 La_2O_3, 1 – 20 Gd_2O_3, 0 – 6.5 ZrO_2, 0 – 10 MgO, 0 – 10 CaO, 0 – 10 SrO, 0 – 10 BaO, 0 – 8 Nb_2O_5, 0 – 8 Ta_2O_5, 5 – 30 ZnO, 0 – 10 Y_2O_3, 0 – 8 It_2O_3, 0 – 8 TiO_2, 0 – 10 Li_2O, 0 – 5 Na_2O, 0 – 5 K_2O, 0 – 1 Sb_2O_3, has a refractive index of 1.72 – 1.83 and a dispersion coefficient of 45 – 55 (US Patent No. 6844279).

Other glass compositions are used for manufacturing the light-conducting core of an optical glass fiber: HBF 3 – HBF 5, HBF 7 – HBF 11, HBF 13, HBF 25 (OST 3-4888–80) and BS 58, BS 80, BS 82, BS 82-1, BS 83, BS 92 based on glasses from the systems BaO – La_2O_3 – B_2O_3 – SiO_2 and ZrO_2 – La_2O_3 – B_2O_3.

HBF 3, HBF 4, and HBF 10 glasses have the composition (%): 13 – 17 SiO_2, 12 – 15 B_2O_3, 0 – 1 Al_2O_3, 12 – 18 La_2O_3, 1 – 4 ZrO_2, 21 – 30 BaO, 0 – 4 Nb_2O_5, 0 – 10 ZnO, 3 – 13 TiO_2, 3 – 23 CdO. The refractive index for these compositions varies within the range of 1.81 – 1.83. HBF 5, HBF 7 – HBF 9, HBF 13, and HBF 25 glasses containing (%): 0 – 10 SiO_2, 9 – 26 B_2O_3, 0 – 4 Al_2O_3, 26 – 40 La_2O_3, 0 – 17 PbO, 0 – 30 CdO, 0 – 4 ZrO_2, 0 – 3 CaO, 0 – 7 Nb_2O_5, 0 – 20 Ta_2O_5, 0 – 7 Y_2O_3, 0 – 10 TiO_2, 0 – 12 ZnO, 0 – 17 WO_3, 0 – 18 GeO_2, 0 – 8 Gd_2O_3, 0 – 5 Ga_2O_3, 0 – 0.3 As_2O_3, have a refractive index of 1.7 – 1.85.

BS 58, BS 80, BS 82, BS 82-1, BS 83, and BS 92 glasses (OST 3-776–80) contain (%): 10 – 70 SiO_2, 0 – 21 B_2O_3, 0 – 3 Al_2O_3, 0 – 20 La_2O_3, 0 – 65 PbO, 0 – 3 CdO, 0 – 4 ZrO_2, 0 – 2 CaO, 0 – 4 Nb_2O_5, 0 – 12 TiO_2, 0 – 12 ZnO, 0 – 22 GeO_2, 0 – 2 CaO, 0 – 1 MgO, 0 – 0.5 As_2O_3, 0 – 1 Sb_2O_3. Their refractive index is 1.6 – 1.8, the dispersion coefficient is 30 – 45, the initial melting point is 510 – 710°C, and the spectral attenuation index is 1 – 6 mm^{-1}.

Boron, silicon, aluminum, and alkali and alkaline-earth metal oxides are the fundamental oxides contained in crown glass. A negative point in melting these glasses is the refractoriness.

Glass compositions for the coating on the optical glass fiber have continued to be high-silica, based on the $R_2O - B_2O_3 - SiO_2$ system. They are usually high-silica glasses of the compositions reported above.

Glass containing (%): 25 – 45 P_2O_5, 0 – 5 Na_2O, 0 – 5 K_2O, 0 – 5 Li_2O, 0 – 15 MgO, 0 – 15 CaO, 0 – 5 ($Na_2O + K_2O + Li_2O$), 0 – 15 SrO, 24 – 40 BaO, 3 – 14 ZnO, 5 – 20 B_2O_3, 0 – 5 Al_2O_3, 0 – 5 WO_3, 0.12 – 0.5 ZnO (BaO), 0 – 0.5 ($Sb_2O_3 + As_2O_3$), has a refractive index of 1.54 – 1.65 (EPB application No. 1477463).

Optical glass from the crown glass group with a refractive index of 1.42 – 1.63 and Abbe number of 53 – 63 contains (%): 36 – 75 SiO_2, 1 – 17 P_2O_5, 0.1 – 8 ($Na_2O + K_2O + Cs_2O + Li_2O$), 0.1 – 8 (MgO + CaO + SrO + BaO + ZnO), 0 – 5 B_2O_3, 17 – 35 Al_2O_3, 0.1 – 8 ($SnO_2 + TiO_2 + ZrO_2$), 0 – 3 WO_3, < 2 Sb_2O_3, and the content of coloring oxides and other inclusions is less than 1% (Germany Patent Application No. 102004034928). For optical glass, the content of coloring impurities should not exceed 0.001%, so that this composition has limited industrial use.

Optical glass containing (%): 65 – 75 SiO_2, 0.1 – 5 Li_2O, 1 – 5 Na_2O, 5 – 20 K_2O, 0 – 5 Cs_2O, 15 – 25 ΣR_2O (R_2O — Li_2O, Na_2O, K_2O, Cs_2O), 0 – 10 MgO, 0 – 10 CaO, 0 – 10 SrO, 0 – 10 BaO, 0.5 – 10 ΣRO (RO — MgO, CaO, SrO, BaO), 0 – 3 ZnO, 0 – 6 B_2O_3, 0 – 1 Al_2O_3, 0 – 2 TiO_2, 0 – 2 ZrO_2, 0 – 3 WO_3, 0 – 2 Sb_2O_3, 0 – 2 F^- (in fluorides) has the following basic characteristics: $n_D = 1.49 - 1.54$, $\upsilon_D = 55 - 65$ (EPB Patent Application No. 1514849).

Optical glass with a refractive index of 1.60 – 1.69, Abbe number of 35 – 45, and initial softening point of 300 – 500°C has the composition (%): 20 – 40 SiO_2, 5 – 20 B_2O_3, 0 – 5 Al_2O_3, 3 – 15 ZrO_2, 0 – 5 (MgO + CaO), 10 – 30 Nb_2O_5, 0 – 10 SrO, 0 – 10 BaO, 0 – 18 ZnO, 5 – 15 Li_2O, 1 – 10 Na_2O, 1 – 10 K_2O, 0 – 1 Sb_2O_3 (US Patent No. 7087542). The glass does not crystallize when held for 30 min in the 500 – 600°C temperature range.

Glass compositions K1 – K5, K8, K14, K15, K18 – K20 are also used for production of the coating on fiber optics elements and have the following composition (%): 55 – 72 SiO_2, 0 – 22 B_2O_3, 0 – 5 Al_2O_3, 0 – 6 PbO, 0 – 6 BaO, 0 – 5 MgO, 0 – 5 CaO, 0 – 22 ZnO, 0 – 11 Na_2O, 3 – 15 K_2O, 0 – 0.4 Sb_2O_3, 0 – 0.5 As_2O_3, and BO 45, BO 50, BO 54, BO 73-1, BO 73-2, BO 77 (OST 3-776–80), including (%): 40 – 70 SiO_2, 10 – 30 B_2O_3, 2 – 6 Al_2O_3, 0 – 3 BaO, 0 – 1 MgO, 0 – 2 CaO, 0 – 2 ZnO, 0 – 9 Na_2O, 3 – 15 Li_2O, 0 – 1 CeO_2, 0 – 0.5 As_2O_3, with a refractive index of 1.47 – 1.53, spectral attenuation index of 208, dispersion coefficient of 57 – 67, and initial softening point of 460 – 540°C.

The temperature curve of the viscosity, which determines both the possibility of preparing light guides and derivative parts and their optical characteristics is one of the basic process parameters of glasses for fiber optics. In using "short" glass, it is usually difficult to prepare a fiber-optic element, especially in the light guide production stage, and the optimum molding temperature narrows. Moreover, "short" glass has the advantage of rapidly forming the light guide or fiber during drawing or overdrawing. To ensure high filling of the end of the part with light-conducting cores and a large transmitted data volume, the viscosity of the coating glass in the molding temperature range must be higher than the viscosity of the glass in the light-conducting core. Since the residence time of the glasses in the hot state in all process sections is high, this results in marked diffusion in the junction of the core and coating. Diffusion is greater the lower the viscosity of the core (the viscosity of the coating is higher and determines the conditions of fiber drawing). The conditions of minimum diffusion also require a minimal difference in the viscosity of the core η_C and coating η_U in deformation. It has been practically established that satisfactory results can be obtained when the $\eta_U : \eta_C$ ratio is within the limits of 2 to 30 [11].

The main problem consists of selecting not only glass for the core of the fiber but also glass with a low refractive index for the coating. The studies in [1] showed that the chemical composition of all highly refractive glass predetermines their low production temperature. Since the viscosities of the coating and core glass should be equal or very close together when the fiber is drawn, the drawing temperature of the coating glass must also be low. Industrial glass with a low refractive index is high-silica glass, has high viscosity, and does not approach core glasses with a high refractive index.

In selecting a pair of glasses for an optical fiber, it is first necessary to consider their "chemical affinity" and select compositions with similar basicity (acidity) to reduce the chemical reaction of the glasses on contact. The compositions of core and coating glasses must be selected so that incorporation of small amounts of any component of one glass in the other will not cause opalescence and crystallization, i.e., any component of one glass should not be "alien" to any other [12].

The problems most difficult to solve in selecting or manufacturing glass for fabrication of fiber parts that arise from the physicochemical processes that take place in the thin core – coating boundary layer are diffusion and convergence of the values of the refractive indexes of both glasses, the appearance of crystallization and microseparation, liberation of gases and formation of bubbles, boiling up, change in color and interpenetration of dyes. The processes that develop on

the core – coating boundary can cause a sharp decrease in the optical characteristics of the part and sometimes also to complete failure of the light-insulating function of the layer. The compatibility of the glasses is the ability of two or three glasses to form a united boundary in the light guide without the appearance of crystallization, bubble formation, and other processes that cause total or partial loss of the light-conducting properties of the individual fibres at the site of the joint or in the glass in subsequent heat treatments. In the boundary layer, one glass can stimulate crystallization and opalescence of the other and sharply worsen the optical properties of the fiber element. Opalescence in a light guide arises during heat treatment in one glass prone to opalescence under the stimulating effect of the glass next to it, and opalescence arises due to an important change in the chemical composition of the boundary layer [3].

Creation of an optical fiber element for any application is due to execution of a series of general process operations: drawing of the fiber, stacking it in a bundle, attaching the fibers in bundles, and optical-mechanical treatment of the optical surfaces of the fiber elements. The prepared element must have constant assigned optical parameters within the limits of the entire working field of the element.

At the end of the 1980s, two basic methods of manufacturing fiber-optic elements were widely developed [13]:

glass rod, which consist of drawing fibres from a glass rod with a high refractive index inserted inside a glass tube with a low refractive index;

draw plate (double crucible method), where the fiber core and coating glass are melted in different chambers of a glass-melting vessel and the fiber is formed after the melt of these glasses has flowed through coaxially positioned filters.

Drawing of the fiber is now proposed in two new methods that ensure the minimum amount of losses in data transmission over fiber-optic communications lines.

The fiber core is formed with the rod and it is then added to the coating tube, the moisture present on the surface is removed by heating and feeding dry gas into the space between the rod and tube. One end of the tube is sealed, then the optical fiber is drawn from the tube. The optical fiber obtained with this method has losses not exceeding 0.5 dB/km (EPB Patent Application No. 1632460).

The core of the light guide is doped with germanium oxide in the proper amount to ensure a difference in the refractive index of relatively pure SiO_2 corresponding to the condition $[GeO_2] \geq 0.3\%$. After drawing, the fiber enters the annealing furnace located below if the cooling rate must be higher than 2000°C/sec, while the annealing time must be greater than the relaxation time (0.03 – 0.8 sec). The annealed fiber then enters the cooling unit where it is forcibly cooled. This method decreases Rayleigh losses due to scattering and gives the fiber high resistance to hydrogen at high drawing unit output (EPB Patent Application No. 1533284).

The invention described in RF Patent No. 1376504 is used in manufacturing fiber-optic elements: inverters, and image converters that rotate it by 180°. This method ensures the alignment of the ends of the preform, eliminates sagging, and provides for formation of thickening and obtaining the assigned length of the joining zone. A graphite sleeve is slipped on the preform, it is attached in an instrument of the lathe type with gypsum, and then heated in an electric furnace lined with quartz brick. When the temperature in the furnace reaches the value at which the core of the preform softens, the preform is rotated with a weight fastened to a block. The angle of rotation is controlled by a dial attached to the axis with a block and stop. The sleeve diameter is 0.05 – 0.15 mm greater than the preform diameter and the length is equal to or 1.2 – 1.5 times greater than the assigned joining zone.

A method for obtaining optical glass fiber preforms by evaporating liquid reagents, feeding a vapor-gas mixture in an inert gas stream into the reaction chamber, precipitation of glass-forming and modifying oxides obtained by plasma pyrolysis of the reagents utilizing oxygen as the plasma-forming gas, and then hardening the porous preform. The method described is distinguished by the use of organic metal compounds as the liquid reagents to widen the range of glass-forming and modifying oxides while preserving the high mass output of product. They are fed into the reaction chamber by passing an inert gas stream through the saturated vapor of the reagents at a temperature selected in the range

$$T_1 < T < T_2,$$

where T_1 is the vapor condensation temperature; T_2 is the temperature of decomposition of the organic metal compound, and the pyrolysis reaction is conducted at a plasma temperature of 2000 – 3000 K.

To ensure normal drawing of the coating fiber simultaneously from the two types of glass, it is necessary for the viscosity of the core and coating glasses to match in a wide range of temperatures. The viscosity of the glasses at the production temperature must be selected especially accurately.

Constancy of the diameter over the length is an important characteristic of the optical fiber. The diameter of the manufactured fiber is kept constant by varying the process parameters that affect the diameter: chemical composition of the material for spinning the fiber, furnace temperature, which determines the viscosity of this material, and the fiber drawing rate. When the diameter is kept constant by adjusting the drawing rate in winding the fiber on the drum, the rotation rate of the drum decreases when the winding radius increases. A drawback of this method is the change in the fiber diameter even at a constant winding speed due to random fluctuations of the temperature in the furnace and the presence of inhomogeneities in the fiber material. Keeping the diameter constant by changing the temperature in the furnace changes the viscosity of the glass at a constant winding drum rotation rate. The drawbacks of this method consist of the inertia of the furnace, which makes the process more expensive, and the drum rotation rate, which affects the change in

the fiber diameter regardless of changes in the temperature in the furnace.

To create optical fiber elements for image transmission, bundles of parallelly stacked fibers with rigorously identical positioning of the fire ends on both ends of the bundle are necessary. Close packing of the fibers at the ends without consideration of the regularity and identity of their position is sufficient in light guides for transmitting light energy and the total flux energy without considering its distribution at the input end. The degree of parallelness of packing of the fiber wound on the bobbin can be increased by unilateral spreading of the fiber over its width.

The following methods are used for stacking the fibers in a light guide: winding and vibration.

The winding method is proposed for laying the fiber on the bobbin in one layer by attaching the fibers in the layer, which eliminates the possibility of their moving relative to each other. After this, single layers are stacked one on top of the other up to a given section of the optical fiber element.

The vibration method is regular placement of a fiber of fixed length continuously entering the mold during the manufacturing process until it is completely filled, it is placed on a platform and continuously vibrated horizontally and vertically. The vibration eliminates the friction between fibers and causes their close regular packing. It should be noted that the frequency and character of the vibration affects the duration of the process and fiber stacking quality [14].

The analytical review of the literature and patents showed that such oxides as Nb_2O_5, TiO_2, La_2O_3, Ta_2O_5, etc., which have a high partial coefficient when added to glass, are currently used in production of the core of the light guide.

However, it was noted that synthesis of glasses in the $BaO – B_2O_3 – La_2O_3 – SiO_2$ system, which are characterized by a refractive index no lower than 1.8 and a minimal tendency to crystallize in the molding temperature range, is the most expedient.

In the entire variety of methods of manufacturing an optical fiber, the following two are the most efficient; they are based on:

doping the light guide with germanium oxide in an amount that ensures the assigned values of the refractive index followed by annealing of the fiber obtained;

forming the fiber core with a rod followed by incorporation in a coating tube and removal of the moisture present on the surface.

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